Scanning Tunneling Spectroscopy of Molecules on Insulating Layers and Superconducting Substrates

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Scanning tunneling spectroscopy is a versatile tool study electronic, vibrational and magnetic properties of single molecules on surfaces. In this talk, I will focus on two complementary applications of this technique.

In the first part, we show that a monolayer of the transition metal dichalcogenide MoS_2 grown on a Au(111) surface acts as an efficient decoupling interlayer for organic molecules from the metal substrate. Molecular resonances within the semiconducting band gap of MoS_2 exhibit widths of only a few meV. This exquisite energy resolution allows to study vibrational excitations within the individual molecules. Details in the set of vibronic resonances on thienothiophene-based molecules allow for their rotamer identification [1]. Furthermore, we study the STM-induced H-abstraction reaction of phthalocyanines on a monolayer of MoS_2 on Au(111). The inert nature of MoS_2 favors the stabilization of an extended π radical, in contrast to the same reaction on a metallic substrate, where the radical state is quenched by charge transfer [2].

In the second part, we study the effect of magnetic molecules on a superconducting substrate. Magnetic impurities in conventional superconductors induce a pair-breaking potential, which leads to bound states inside the superconducting energy gap. These states are called Yu-Shiba-Rusinov (YSR) states, and can be probed by scanning tunneling spectroscopy at the atomic scale. The energy of these states depends on the strength of both exchange and potential scattering. Here, we investigate an Fe porphin molecule on a superconducting Pb(111) substrate. We show that we can tune the strength of the magnetic exchange scattering with the Cooper pairs by approaching the STM tip toward the molecule. In the presence of the forces exerted by STM tip, the YSR states continuously shift through the superconducting energy gap, eventually even crossing the Fermi level. This model system allows to study the quantum phase transition between a screened and unscreened spin state [3].

[1] N. Krane, C. Lotze, G. Reecht, L. Zhang, A. L. Briseno, K. J. Franke, ACS Nano 12, 11698 (2018).

[2] G. Reecht, N. Krane, C. Lotze, K. J. Franke, ACS Nano 13 7031 (2019).

[3] L. Farinacci, G. Ahmadi, G. Reecht, M. Ruby, N. Bogdanoff, O. Peters, B. W. Heinrich, F. von Oppen, K. J. Franke, Phys. Rev. Lett. 121, 196803 (2018).